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AN INVESTIGATION OF REQUIREMENTS TRACEABILITY TO SUPPORT SYSTEMS DEVELOPMENT

by

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An empirical study, utilizing focus group and protocol analysis techniques, was conducted with students from the Naval Postgraduate School. Their input, along with current literature, was used to explore factors to be taken into account while developing a model of traceability, and the appropriateness of the two data collection methods in future research.

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An Investigation of Requirements Traceability to Support Systems Development

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ABSTRACT

A primary concern in the development of large-scale, real-time, complex, computer-intensive systems is ensuring that the system meets the specified requirements. Further, the requirements themselves evolve and undergo many changes during the development process. In such a context, it is essential to maintain traceability of requirements to various outputs to ensure that the systems meets the current set of requirements.

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TABLE OF CONTENTS

I. INTRODUCTION

A. OBJECTIVES OF THE RESEARCH

The goal of this thesis is to conduct an experimental study to help derive requirements for designing a traceability method at the level of systems design, relating requirements to all system components. Such an experiment should provide the semantics of the various traceability linkages or relationships between requirements and various system components. It should also provide mechanisms for reasoning with traceability information to support systems development and maintenance activities.

A first step towards accomplishing this objective is to understand the critical issues that relate to the capture and use of traceability information in systems development. A basic premise in the current research, from which results are reported in this document, is that development of a model of traceability could be geared toward the needs of stakeholders at various stages of the systems development process.

A variety of stakeholders is involved in the systems development process, including project sponsors, project managers, analysts, designers, maintainers, testing personnel, and end users. The approach used in this research to identify stakeholders' needs has been empirical. Our study explores

the traceability needs of various stakeholders and identifies the critical issues that need to be addressed in developing an initial model of traceability. This study was conducted with graduate students of a systems analysis and design course, in a simulated systems development environment. The results of this study are being used in designing a comprehensive study involving real stakeholders in large-scale, complex, real-time systems development efforts.

Another objective is to evaluate different research tools for data collection and analysis to aid in the design of the comprehensive study.

Given the above objectives, the following questions are addressed:

- What are appropriate methodologies that could be used in a comprehensive study on traceability in complex, large-scale, real-time systems development environments?
- What are the critical issues in the development of a model of traceability supporting various stakeholders in systems development?

B. SCOPE AND LIMITATIONS OF THE STUDY

The current study employed novice systems designers in a simulated design setting. It should be noted that this research is designed to provide insights only into issues that need to be investigated further, rather than to provide conclusive results. Another constraint was the lack of resources to evaluate comprehensively the current tools that support representation of traceability information.

C. METHODOLOGIES

Two tools were employed in this research: focus group interviews for idea generation and protocol analysis to study problem-solving behavior.

D. ORGANIZATION OF DOCUMENT

Chapter II provides background information on the general topic of traceability, a discussion of some of the current traceability tools available, and the uses of traceability in the Department of Defense (DoD) and Department of the Navy (DON).

Chapter III describes focus groups and protocol analysis and their applications to this research. Each of the techniques, and why they were selected for the particular requirements of our research, is explained.

Chapter IV provides an analysis of data collected, utilizing focus groups and protocol analysis techniques. It discusses the major findings and relates them to current literature. This discussion elaborates on the initial findings reported by Ramesh and Edwards. (Ramesh and Edwards, 1992)

The final chapter presents an initial model of traceability, draws conclusions based on research data, and makes specific recommendations resulting from the research effort. The chapter concludes with recommended areas for

additional research. (A more detailed version of this document is available as Ramesh et al., 1992.)

II. BACKGROUND

A. WHAT IS TRACEABILITY?

A number of different definitions can be provided for traceability, depending on the context in which the term is used. Norman Schneidewind (1982) depicts traceability as a means of maintenance, focusing on the maintenance phase to discover sources of error. He defines traceability as "the ability to identify the technical information which pertains to a software error which has been detected during the maintenance phase and thereby trace the error to the applicable design specifications and user requirements...." (Schneidewind, 1982, p. 4).

Whereas Schneidewind's concern for traceability is at the software level, Greenspan and McGowan (1978) are concerned with the use of traceability to effect changes in the entire system at various levels. They offer a broader definition of traceability as being:

> the property of a system description technique which allows changes in one of the three system descriptions—requirements, specification, implementation—to be traced to the corresponding portions of the other descriptions. The correspondence should be maintained throughout the lifetime of the system. (Greenspan and McGowan, 1978, p. 79)

To achieve the abovementioned correspondence, Agusa et al., postulate that two-way traceability is required. They

infer traceability is bidirectional by saying, "A requirements description is traceable, if each portion of the description can be traced to an originating requirement in its predecessor, and to a successor description." (Agusa et al., 1984, p. 226)

While all of the above definitions focus on change/maintenance, other aspects of traceability are not emphasized. Michael Edwards offers a more generic and inclusive definition of traceability as a technique used to "provide a relationship between the requirements, the design, and the final implementation of the system." (Edwards, 1991, p. 3-8)

B. TRACEABILITY TOOLS AND CURRENT EXPECTATIONS

The initial concern with traceability was that of providing document traceability. Traceability within documents assures that the source of information is distinguishable.

There are a number of existing traceability tools developed by industry. Based on the documentation made available by software developers, four tools are discussed below. Since these tools vary widely in their applications, and as yet there are no industry standards for them, no attempt at comparison is made.

One of the earliest systems to capture and use traceability data was Automated Requirements Traceability

System (ARTS), a bookkeeping program developed to manage the requirements of a large, error-prone aerospace system. ARTS operates on a data base that includes systems requirements and their characteristics. It allows for automated tracking of requirements as they are partitioned and apportioned to lower-level requirements. ARTS provides upward and downward traceability, database management, and output operations on requirement-related attributes selected by the user. Like ARTS, other current tools often focus on the database management issues related to maintaining links between requirements and differing components of the system.

Some of the traceability tools on the market today provide for manual parsing and grouping of functional requirements. One such tool is Cadre's Teamwork/RQT. Some of this tool's other capabilities include point-and-click allocation of requirements to targets, navigation through allocation channels to integrate the entire life cycle, and the ability to propagate allocations between parent and child entities.

Cadre describes Teamwork/RQT and its concept of requirements traceability as follows:

> The purpose of requirements traceability is to reveal the mapping between requirements and the deliverable components which are intended to satisfy them. Proof of compliance is a two-step process: (1) Show the correspondence of requirements to deliverable components. A table which shows this correspondence is called a *traceability matrix*. (2) Show that the corresponding deliverable components correctly satisfy the requirements. (Cadre Technologies, Inc., 1990, p. 6)

Teledyne Brown Engineering makes the traceability tool Requirements Tracer (RT). Concerning its product, Teledyne Brown states:

> The RT Tool can be used throughout the entire system life cycle (analysis, design, implementation, testing) to define, analyze, and trace system requirements. From a database of natural language requirements for which various criteria have been defined, relationships between requirements can be defined. The RT Tool then creates a requirements traceability matrix for assistance in verifying the proper allocation of all requirements. The user may then generate customized reports which output a user-selected set of information. (Teledyne Brown Engineering, 1991, p. 1)

Capabilities of RT include such tracing mechanisms as parent/child relationships (and how to determine them), functional hierarchy, keywords, attributes, querying, requirements extraction, and customized report generation. Requirements can be allocated to functions or subfunctions by either direct entry or selection from a previously defined list.

RTM, made by Marconi Systems Technology, is yet another current traceability tool. In discussing traceability benefits, the Marconi company affirms:

> In the verification and validation process, traceability is the only technique for assessment of consistency between different lifecycle phases prior to coding.... Ultimately, acceptance testing is a direct assessment of the integrated system against the statement of requirement, i.e. another form of traceability.... Traceability is thus a major technique for risk management on a project. (Marconi Systems Technology, 1991, p. 17)

Requirements and Traceability Management (RTM) provides project configurability (specifying where traceability is

wanted), requirements engineering, requirements traceability, and documentation. More than one type of link is possible between objects.

Current traceability techniques tend merely to provide mechanisms to represent relationships without providing any guidance on what useful relationships are and how this information will be useful during the lifecycle of a system. Contemporary methods yield some traceability through simple linking techniques that relate requirements to design. These methods, however, do not provide any formal definitions of traceability linkages.

C. TRACEABILITY IN DOD AND DON

As one of the world's major users of large-scale, computer-based systems, DoD takes a detailed approach to the dilemma of specifying systems requirements. DoD standards may provide even an instructive checklist for systems content.

In February 1988, DoD specified its requirements for systems development in its Military Standard DoD-STD-2167A. This standard mandates that requirements be traceable through the entire system. DoD-STD-2167A formalizes the tracing of requirements (in documents) from the original set entailed by the customer, to the contractor's written requirements specifications, and to the design, test procedures, and results. However, the standard states only that traceability is required, not <u>what</u> information is to be maintained to

achieve this. A clear definition of the types of information, or relationships between various systems components that are part of a traceability scheme, is lacking.

Having a precise method for ensuring that requirements are met by the design is vital. DoD currently delineates its requirements to contractors in documents that are developed by numerous specialists in a format that may be thousands of pages long. With declining defense dollars, systems must be cost-effective, and be able to adapt to major changes during their lifecycle.

One of the foremost issues in developing an efficient and effective system involves the maintenance of consistency between requirements and design. This consistency entails meeting the initial requirements and maintaining requirements, design, and implementation consistently throughout the entire systems lifecycle. A key element included in a request for proposal must be traceability, guaranteeing that the current set of requirements is met by the evolving system.

The current method used by the Navy to specify requirements uses mostly a narrative, English format with supporting diagrams and charts. Ambiguities are frequent, as English specifications are inexact. If specifications are formally stated and can be transformed into designs in a formal manner, traceability between requirements and designs is a by-product of the design process itself. However, since

most specifications are written in English, mechanisms are needed to capture traceability information explicitly.

In light of some recent systems malfunctions that produced catastrophic consequences (major telephone service shutdowns, for example), it is now commonly understood that changes to intricate systems can result in unforeseeable and disastrous effects to important national defense systems. These problems possibly could be avoided if correct traceability methods are used along with proper maintenance of systems.

III. AN EXPERIMENTAL APPROACH FOR DETERMINING TRACEABILITY REQUIREMENTS

A. INTRODUCTION

Our data collection strategy involved a two-pronged approach: focus group interviews for idea generation and evaluation, and protocol analysis of problem-solving behavior. This chapter discusses these two techniques and the design of the study that employed the two methodologies. Details of the research setting and subjects, as well as the reasons for the use of data collection techniques, are provided.

B. FOCUS GROUPS

1. What Are Focus Groups?

A focus group interview is a semi-structured exchange among a small group of people. It is not a rigidly constructed question-and-answer session, nor is it a free dialogue between group members; the group has a clear agenda. According to Richard Krueger (1988):

> A focus group can be defined as a carefully planned discussion designed to obtain perceptions on a defined area of interest in a permissive, non-threatening environment. The discussion is relaxed, comfortable, and often enjoyable for participants as they share their ideas and perceptions. Group members influence each other by responding to ideas and comments in the discussion. (Krueger, 1988, p. 18)

Focus group interviewing is possibly the most consistent qualitative marketing technique in use today. (Templeton, 1987, p. 3) Today, in many marketing research organizations, group interviews are nearly as common as the traditional survey questionnaire.

Focus groups were originally called focused interviews. They were first used in the 1930s by social scientists as an alternative to the technique of using an interviewer with closed-ended questions and one respondent; the idea was that multiple respondents could make comments on issues they believed to be important, while interacting with one another. In the 1940s, focus groups were used in the evaluation of audience responses to radio programs, and the observation of the effectiveness of wartime propaganda efforts. In the 1990s, although much of what we know about the focus group technique has come from market research, all professions, from academia to diplomacy and politics, to the social science and business worlds, are adopting this eminently versatile method.

The focus group interview is a highly flexible tool and as such is extremely popular. Focus groups are appropriate for exploratory analysis when little is known about a topic; for generating ideas and research hypotheses; for determining how groups of individuals think about current issues; for producing information, uncovering potential

problems, and encouraging creativity. Today, focus group interviewing is considered to be a valid scientific method. An example of a successful use of this technique is documented by Stewart and Shamdasani (1990).[1]

Focus group interviewing today usually involves seven to 12 individuals who discuss a particular topic under the direction of a moderator, who promotes discussion and ensures that the group stays on the subject. Smaller groups may be dominated by one or two members, while larger groups are difficult to manage, and limit participation by all members. A typical session will last from one-and-one-half to two-and-one-half hours.

2. Effectiveness of Focus Groups

Focus groups may be used as a method for testing hypotheses, especially when the researcher has strong reasons to assume his/her hypotheses are correct. Some critics, however, maintain that focus groups do not provide "hard" data

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[1]The focus group technique was used by the Reagan administration in 1988 (an election year) to determine the character and extent of the knowledge/opinion gap between the American public and government officials, in regard to American-Soviet relations. The Reagan team asked two suburban Philadelphia focus groups of "average citizens" to examine the ways in which a future Soviet-American summit meeting could be believably presented to the American people while simultaneously garnering popular support. Based on focus group responses, the team chose for the trip the theme, "A brighter future and a safer world for all people." The Philadelphia groups also helped determine some of the events of the trip, including with whom President Reagan would meet. (Stewart and Shamdasani, 1990, pp. 124-126)

and that group members may be atypical of a larger population. But even the critics acknowledge that focus groups are useful for exploratory research where little is known about a topic.

The more commonly lauded uses of focus groups include:

- generating research hypotheses that can be submitted to further research and testing, using more quantitative approaches;
- stimulating new ideas and creative concepts;
- diagnosing the potential for problems with a new program, service, or product;
- creating impressions of products, programs, services, institutions, or other objects of interest; and
- learning how respondents talk about the phenomenon of interest.

Some advantages of focus groups include:

- They are quicker and less costly than individual interviews.
- Direct contact with respondents allows for probing and clarification; the respondent can use his own words to express himself.
- Through group interaction, members tend to influence and change each others' opinions, and this shift can be studied; information and insights are provided that would not be available without the group's interaction.
- Focus groups have a dynamic effect, encouraging creativity.
- Results are believable and easy to understand.
- There is much research and theory related to focus groups.

Some disadvantages of focus groups include:

- The sample size is limited.
- Groups may vary widely in their enthusiasm levels and responses.
- Responses are not independent and may be biased by one or more participants.
- Summarization and interpretation of responses may be difficult.
- The moderator has less control in a group setting than in a one-on-one interview.
- The moderator may bias results.

According to Stewart and Shamdasani:

> We should not overlook the cases in which focus groups alone may be a sufficient basis for decision making. One example in an applied research setting would be the identification of flaws or serious problems with a new product or program that would necessitate redesign. (Stewart and Shamdasani, 1990, p. 17)

When little is known about a particular subject, there are few good alternatives to focus groups. Focus groups are quicker and less expensive than individual interviews; one simply must recognize the potential for obscuring individual responses.

3. Group Dynamics

It is the characteristics of group members in relation to one another, and not just individual differentiation, that determine group behavior and performance. Focus groups should be structured to facilitate the goals of the researcher, while avoiding manipulation of the final results.

A recurrent supposition regarding focus groups is that superior data are obtained when members are strangers. However, Stewart and Shamdasani state:

> Generally, focus group sessions are preceded by 'get-acquainted' and 'warm-up' sessions that usually provide participants ample opportunity to get to know one another. Thus, the issue of acquaintanceship appears to be a matter of degree in most focus groups, and its influence appears modest at best. (ibid, p. 34)

Another concern regarding focus groups is the members' backgrounds.

> In general, interaction is easier when individuals with similar socioeconomic backgrounds comprise the group. Similarity of abilities, level of intelligence, and knowledge tends to facilitate communication at the same wavelength. Similarly, in culturally and racially homogenous group situations, it may be easier to encourage member participation. This suggests that focus groups should be designated to maximize interaction by assuring similarity with respect to socioeconomic status. (ibid, p. 38)

A highly homogenous group may be able to move through many questions quickly, while a highly heterogenous group may belabor even a couple of questions. But a small degree of variation within group characteristics is often a helpful way to obtain the contrast and variation that spark lively discussions.

Krueger advises:

> The focus group technique works well when all participants are on an equal basis....Participants should be grouped with care. Participants should be placed with others at the same level or status in the organization. (Krueger, 1988, pp. 96, 167)

4. The Moderator

When a moderator/interviewer has little experience or prior knowledge in a field, the focus group technique can be ideal, as David L. Morgan (1988) argued:

> When the researcher is relatively new to an area, or puts a priority on not repeating the received wisdom in a field, focus groups have much to offer. The fact that group interviews can produce useful data with relatively little direct input from the researcher may be a distinct advantage, especially in comparison to other interviewing techniques. (Morgan, 1988, p. 21)

A designated moderator/interviewer does away with much of the distraction associated with the group having to develop its own leadership. With respect to the discussion, the moderator may be highly directive or very non-directive—letting the discussion flow naturally as long as it remains on the topic. It is quite common for an interviewer to start with some general questions, then focus on more specific issues as the group proceeds.

The amount of direction provided by the interviewer does influence the type and quality of the data obtained from the group. The amount of structure and direction by the moderator must be determined by the broader research agenda, including types of information sought, degree of detail the information requires, and the manner in which the information will be used.

Discussion of issues relevant to the needs of the researcher occur most readily when the moderator takes a more directive and structured approach. When this occurs, however,

participants discuss what is important to the researcher, not necessarily what they consider significant.

5. The Interview Guide

In setting the agenda for a focus group, the moderator must choose from among research questions to create the interview guide. An alternative, available to a researcher conducting several focus groups, is the rolling interview guide. When multiple groups are involved, the interview guide developed for the first group is revised and used for the second one, whose guide will again be revised before it can be used for the next group, and so on. This technique makes the best use of multiple focus groups, permitting information to be refined over time as more information is obtained about a subject.

6. Analyzing Focus Group Data

According to Stewart and Shamdasani:

> The most common purpose of a focus group interview is for an in-depth exploration of a topic about which little is known. For such exploratory research a simple descriptive narrative is quite appropriate. More detailed analyses simply are not necessary or efficient. (Stewart and Shamdasani, 1990, p. 102)

For analyzing the content of focus groups, the cut-and-paste method is immediate and cost-effective. The use of this technique entails reading a transcript and identifying sections that are pertinent to the researchers' topic. Material related to each topic is then identified and marked.

Next, the marked text may be cut out and sorted (using either scissors or a computer) for use in the analysis.

Cut-and-paste is a useful technique, but often relies on the judgment of a single analyst. Usually it is preferable to have two or more analysts code the focus group results independently.

C. PROTOCOL ANALYSIS

1. Definition of Protocol Analysis

Protocol analysis can be defined as "the process of translating the chaotic collection of information, which is derived from the protocol, into more useful and meaningful representation." (Vitalari and Dickson, 1983, pp. 948-956) In a more general sense, protocol analysis can be thought of as the collection and analysis of verbal reports (called protocols) made by subjects while they perform a specific task. In most cases, protocol analysis is used to generate a mechanism for tracing a subject's thought process. Ericsson and Simon distinguish between two different types of verbalization procedures—retrospective verbalization and concurrent verbalization. Retrospective verbalization refers to the technique in which the researcher asks the subject for information about his/her thought processes after the task is completed. Concurrent verbalization, used in this research, refers to a technique in which the subject is asked simply to

verbalize his/her thought process while working on a task. (Ericsson and Simon, 1980, pp. 24-26)

Concurrent verbalization procedures have been used extensively in the study of human problem solving, including such areas as general problem-solving behavior, physics problem-solving behavior, stock selection, pediatric cardiology, and accounting information decisions. (Vitalari, 1981, p. 82)

2. Validity of Concurrent Verbalization

According to Vitalari, despite the extended use of concurrent verbalization, considerable contention surrounds its use. Some researchers have questioned the validity of verbal reports. The four major issues under contention are:

- skewed verbalization of true thought process
- incompleteness
- interference with thought process
- subjective bias during analysis

The first major issue is that if the subject articulates his/her own thought process, he/she is allowed to decide <u>how</u> it will be verbalized. Therefore, the thought process is different from the one verbalized. The second issue, incompleteness, argues that the task of verbalizing interferes with the main task; hence, the subject is only able to verbalize a small part of the actual thought process. The

third issue, interference with thought process, refers to the researcher probing the subject to explain his/her reasoning, etc., during the experiment. The fourth issue, subjective bias, occurs if the researchers' analysis of the data is different from what is implied by the verbalizations. (Vitalari, 1981, pp. 83-84). However, this bias is prevalent in virtually any data analysis technique.

Some of the ways to safeguard against the above problems include ensuring the researchers do not probe the subjects during the experiment, and having independent researchers analyze the protocols. (ibid, pp. 87, 89)

3. Evaluating Protocol Analysis Data

A wide range of methods to evaluate protocol analysis data is reported in literature, varying from a quick count of the occurrence of certain words in the protocols, to an extensive analysis of all the elements in the tasks under investigation. The method chosen to analyze the concurrent verbalizations in this research was the simple technique of searching through the protocols for unique ideas, thoughts, etc., relating to traceability issues.

D. STUDY DESIGN

1. Subjects and Subject Training Before Experimental Study

A total of 58 subjects were used for this study. They came from a Masters program in Information Technology at the

Naval Postgraduate School. To prepare the subjects for our experiment, they were given a case study conducted in a graduate level Systems Analysis and Design course. Each subject was a member of a small project team, consisting of three or four students each. The case study was based on a real-life, large-scale project and had been used successfully in similar studies (Ramesh and Dhar, 1992, p. 4), and involved processing of customer orders in a utility company. The case analysis entailed a variety of data-gathering methods during the analysis phase, including informal descriptions of user needs, simulated client meetings, and actual documents from real-life situations. The major outputs developed by the participants included requirements statements, data flow diagrams, entity-relationship diagrams, database design, and implementation.

This training case was selected for several reasons:

- it had been developed after an extensive domain analysis was conducted, based on a real-life system developed by a large information systems consulting organization;
- it had been used successfully in several settings, including protocol analysis of group problem-solving behavior;
- the problem domain was familiar to the students, as they had personal experiences with the services provided by the system;
- real-life data could be easily collected from a utility company and used in the analysis and design of the system when necessary (e.g., rate schedules were collected from the local utility company and used in systems design);

- the problem was sufficiently complex to cover all the basic elements of systems design; and
- the problem could be partitioned so that different groups of students would be assigned projects that could be completed within a reasonable time frame.

These activities were completed during a period of over two months prior to the subjects' participation in the focus groups. Many subjects had extensive experience in domains other than computer-based systems development, such as shipbuilding and aviation maintenance, where concepts of traceability are widely recognized.

2. Task Design Using the Focus Group Technique

Six focus groups were conducted over a two-week period following the subjects' completion of their case studies. Each group (approximately eight to 10 subjects) consisted of two or three project teams and each session lasted roughly one-and-one-half hours. The focus groups were conducted in a semiformal setting—a meeting room equipped with facilities for audio/video recording. The following steps were utilized for each session:

- a short warm-up period, during which everyone, including the moderators, was introduced and the ground rules of the interview stated;
- a predisposition discussion about the traceability issues that needed to be explored, including general discussions on the various stakeholders' interest in traceability; and
- a collective and comparative discussion of all topics, followed by a wrap-up of the discussion. During this

segment, the participants were prompted for their summaries of what was discussed in the group meeting.

3. Task Design Using the Protocol Analysis Technique

After the focus groups were conducted, one or two participants from each project team volunteered to participate in the protocol analysis portion of the experiment. This exercise started with each subject participating in a few short warm-up examples to get him/her accustomed to thinking aloud. Following these exercises, participants were handed written instructions (see Figure 1), followed by a question/answer segment, during which clarification of their questions was provided. The exercises were conducted individually, with each subject working in a semi-private area; his/her thoughts, as they were verbalized, were tape recorded. The researchers monitored the sessions to operate the audio equipment and to prompt the subjects to verbalize their thoughts, when necessary. Each session lasted from 30 to 75 minutes. The recordings were transcribed verbatim, then searches were conducted throughout the transcripts for key words, phrases, concepts, or ideas that dealt with issues relating to traceability. Figure 2 represents a sample transcript from the exercise.

4. Rationale for Using Focus Groups and Protocol Analysis

In light of the information detailed above, we felt ourselves to be on firm empirical ground in using focus groups

EXERCISE INSTRUCTIONS

You have just been appointed as the project team member in charge of creating and maintaining traceability. You are required to review your project and see if you can find/assign any traceability information in the form of relationships or linkages between various components during the systems development process including:

(1) requirements
(2) Data Flow Diagrams
(3) ER Models
(4) Data Base Design
(5) Implementation

The traceability information should be geared toward supporting various stakeholders involved with the development and use of the system. Specifically, you may consider the needs of the following categories of stakeholders:

project sponsor
project manager
systems analyst
systems designer
maintainer
end user manager
end user (other)
training personnel

Please attempt to complete the exercise in as much detail as possible within the allotted time. It is important that you cover every aspect of traceability that you consider important. Therefore, you may choose to provide only a few examples of each aspect of traceability information for each category rather than being exhaustive. While doing this, also talk about what characteristics a tool that might help you in creating and maintaining traceability information should have.

Finally, please note that this exercise is not intended to be a test of your problem solving expertise or as an evaluation of your project. We are interested in understanding the problem solving behavior and are therefore primarily interested in the process you go through. Thank you very much for your time.

Figure 1. Exercise Instructions

Having been exposed to some systems that provide relatively good traceability in that the traceability can be accomplished to a certain degree on line with, with system help, I can tell that we don't come anywhere close to that, but that is what I would like. I would like for the system to be able to answer questions at the various levels. For example, for a, for a, at the project sponsor, project manager level, I would like them to be able to stick in test data which they actually know the inputs are and what the outputs should be and submit it to the system and ask for the output at various levels. For example, after, after they collect a certain amount of meter readings, eliminating all other factors, and ask how much would the charge be and they should be able to, in my opinion, get a number ??. And if they do have a final bill amount, they should be able to say, OK, I want a detailed report of all of the factors that went into it-from, from what type of table was used to come up with the tax rates, what types of tables were used to come up with the rates for a certain type of customer such as agricultural, as opposed to residential, to how many hours were used at peak time. I like the system to be able to answer queries to that affect. So, that points, that points, if our system were able to do that, that's the kind of traceability that, that both our end user manager and our end user, end user phone center operator, would, would need and find useful.

(Pause) As far as the ER diagram and data flow diagrams, it occurs to me that the place where it would, where they, there's two, two place, two stakeholders that would, that that would be most important to are the system maintainers and the systems designers. I know for a fact as we were designing the system, we looked, we looked often at the requirements kept on going back very, very, very often. As a maintainer who does not have the same knowledge that we had from the start who has to learn the system from scratch after it is built and working, he, ER diagrams and data flow diagrams both on line and in hard copy as we have them, would definitely be important part of traceability.

Figure 2. Sample Partial Transcript

for our research. The following are specific reasons we used these techniques:

- The focus group is a valid, proven research tool in areas such as traceability, where not much is known about the topic and where generation of ideas and hypotheses for further study is desirable.
- There has been ample research on the focus group technique to give us a solid background in using it; at the same time, focus groups may be conducted informally enough to work well within our academic setting.
- As mentioned above, when moderators are new to a research topic, such as we were to traceability, they are actually at an advantage in not reiterating the established knowledge of the field.
- The groups of students attending the Naval Postgraduate School were acquaintances who have similar socioeconomic backgrounds and levels of intelligence. At the same time, there was a small degree of variation (students from different Navy backgrounds) that Stuart and Shamdasani called for in the groups.
- Since it is preferable to have two or more analysts coding focus group results independently, this technique has proven to be suitable for a multi-person research team.
- The rolling interview technique allowed us to learn as we went along and to benefit from conducting multiple groups.
- As previously mentioned, a simple descriptive narrative, rather than technically detailed analysis of the focus groups conducted is the most appropriate method for analyzing our data.

In view of the proven track record of protocol analysis in numerous diverse areas, it was decided this technique could also prove beneficial to our research. Some specific reasons for choosing this method include:

- Protocol analysis has been successfully used previously in the area of problem-solving behavior, and conducting an

empirical study of the thought processes that various stakeholders might have concerning traceability was an important focus of this research.

- A sufficient number of subjects who had prior exposure to concepts of traceability in domains other than computer-based systems development and who had participated in a systems development (as a part of the case study) were readily available .

- The issues under contention, mentioned in Section C above, are minimized in our study, since the safeguards discussed were implemented during the exercise.

IV. RESEARCH FINDINGS AND DISCUSSION

A. INTRODUCTION

In this chapter, we discuss results from the analysis of data collected during focus groups sessions and protocol analysis. First, we review the context in which traceability information is likely to be used during systems development, i.e., from the perspectives of key stakeholders involved in the systems development process. This is followed by a discussion of major issues that need to be addressed in the development of a model of traceability, and the mechanisms to support the capture of, and reasoning with, this information. Findings from relevant literature are included to elucidate the main issues.

B. STAKEHOLDERS

A number of stakeholders are involved in the systems development process, including project sponsors, project managers, analysts, designers, maintainers, and end users. The development of a model of traceability should be geared towards these various stakeholders in the systems development process. This section will address these key stakeholders and what their concerns/uses for traceability encompass.

1. Project Sponsor

A project sponsor is the individual or organization that provides funding for the system being developed. ("The project sponsor is mostly concerned about cost overruns and a finished product.")[2] Besides assuring the sponsor that genuine requirements are met, traceability also provides a mechanism to verify that unnecessary "wouldn't it be nice to have" features are curtailed. In so doing, the sponsor can avoid potential cost overruns, schedule slippages, and similar impediments.

2. Project Manager

The project manager is the supervisor who "...plans, delegates, and controls progress to develop an acceptable system within the allotted time and budget." (Whitten, et al, 1989, p. 99) He/she is the key person held accountable for a project from start to finish, and needs to ensure only essential requirements are met. In general, he should make sure the project is finished on time, within the given budget, and that ("the project/system does what it was intended to"). A project manager uses such techniques as tracking milestones, etc., to ensure his/her responsibilities are accomplished. ("The project manager needs traceability for...tracking

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[2]This is a direct quote from a subject participating in the protocol analysis exercise. Henceforth, all quotes from a subject, made either in a focus group or during the protocol analysis exercise, will be enclosed in parentheses and quotation marks, but no specific reference will be made.

milestones and...keeping tabs on projects.") According to Brown, "Traceability provides for ease in determining phase completion and product completeness." (Brown, 1987, p. 9) Traceability will also help the project manager determine when he/she has "covered all requirements so you can stop working on a project." (Cadre Technologies, Inc., 1990, p. 4) Based on the above reasoning, the project manager is one of the primary beneficiaries of traceability.

3. Systems Designer/Analyst

"A software designer often needs to trace from requirements objects to the corresponding design objects or from source code to its corresponding design or requirements objects." (Nejmeh, et al, 1989, p. 981) This use of traceability will help a systems designer determine if all requirements have been considered and specifications validated. Further, the designer needs to understand why design objects satisfy particular requirements. ("A systems designer wants traceability in order to go back to the logic.")

The systems designer is also involved following systems implementation. ("To the systems designer, traceability is extremely important as far as implementation goes ... [because he] is going to have to accommodate any design changes and [determine] the relative impact within the organization. If they don't have good traceability in the

system, he [systems designer] may implement a change which ... may even cripple the system.")

4. Maintainer

Maintainers are the personnel who make repairs to the system, once it has been implemented, and updates it to keep up with changing requirements. They, in addition to project managers mentioned above, are key beneficiaries of traceability. Once a change is required, a maintainer needs to be able to trace that change back to the requirements that necessitated or triggered it, and to pinpoint which parts of design/implementation are effected by the change. ("The systems maintainer wants traceability for ... tracing to a piece of code, for updating, and for changeability.")

5. End Users

Different levels of end users will employ traceability in varying degrees. On one end of the spectrum is the casual end user who "may only use only a specific on-line program on an occasional basis" and "may never become truly comfortable with the terminal or the program." (Whitten, et al, 1989, p. 578) An example of a casual end user is a data entry clerk. On the other end of the spectrum is the dedicated end user, "one who will spend considerable time using specific on-line programs. This user is likely to become comfortable and familiar with the terminal's operation." (ibid, p. 578)

The casual end user may have little or no need for traceability. ("[Casual end users] are pretty much just concerned about using the system and don't really care or have any power over where it came from or why it is the way it is."; "I wouldn't see where they would be interested in the traceability of the design and the functionality of the system.") If these end users had access to traceability, it could be "dangerous" or could lead to unauthorized changes to the system. In particular, ("He [casual end user] is too far removed and should not be attempting to change things. He is not to be trusted with a 'little' knowledge."; "It is dangerous for him to use traceability.")

Dedicated end users, however, have more applications for traceability. Some subjects noted: ("The more sophisticated end user needs traceability to manuals to see how to achieve the functionality specified in requirements documents[3] and traceability to programs, via queries, to modify them to achieve functionalities."; "For the dedicated end user, traceability is beneficial for understanding reasoning...and for troubleshooting.") As for the end user manager, ("He needs traceability for accountability,[4] for attempting to improve on a prototype ... and to enhance documentation.")

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[3]Traceability to documents is addressed in a later section.

[4]Accountability is addressed in a later section.

C. MAJOR ISSUES

Our studies brought out several issues that need to be carefully examined to facilitate the development of a model of, and mechanisms to capture and use, traceability information. Following are some key issues we discovered, both in focus groups and protocol analysis, while evaluating the data:

1. Bidirectional Traceability

Bidirectional traceability implies both forward and backward traceability. Forward traceability is provided if each requirement specifically references a design component. In other words, forward traceability allows one actually to see where requirements materialize in the finished system. In the context of software design:

> The forward traceability...is especially important when the software product enters the operations and maintenance phase. As code and design documents are modified, it is essential to be able to ascertain the complete set of requirements that may be affected by those modifications. (Dorfman and Thayer, 1990, p. 27)

Backwards traceability is provided when a requirement is referenced by a design element. In the context of definition of requirements from source documents, "Backward traceability...to previous stages of development depends upon each requirement explicitly referencing its source in previous documents." (ibid, p. 27) Here, bidirectional traceability indicates that a requirement derived from a

former requirement has been considered, and that any new requirement can be traced back to a preceding one.

Though one of the most critical uses of traceability is ensuring that a design element satisfies a requirement, the existence of such a link may not answer the question: are the functionalities of the design element *required by* requirements? To help answer this question, links need to be bidirectional in order to allow requirements to be traced forward from requirements to systems components, and backward, from systems components to requirements.

2. Criticality of Requirements

A useful way of identifying critical requirements is to relate them to the central "mission" of the system. Business processes that *generate* requirements could be identified, and requirements evaluated with respect to such processes, to arrive at a classification. For example, traceability should address the issue of how the requirements are arrived at. This necessitates a mechanism to represent the *elaboration* and *refinement* of requirements, from the central mission or business processes that *generate* them.

A good traceability scheme should recognize that all requirements are not equal in level of significance or criticality. Different levels of detail must be established in order to minimize the overhead involved in capturing and using traceability information. It may be unnecessary or even

undesirable, considering the overhead involved in maintaining traceability, to maintain linkages between every requirement and every output created during the systems design process related to it. Costs must be justified by the benefits. It is essential to identify critical requirements and maintain traceability from those requirements to the various systems components.

The need to relate mission criticality to a traceability scheme was considered important by many subjects in the focus groups: ("We just have to realize that it [traceability] is not necessary for mundane decisions."; "Traceability is great for the critical stuff.")

3. Design Rationale

Another important component of traceability is design rationale information. On the need for design rationale, MacLean states: "To understand why a system design is the way it is, we also need to understand how it could be different and why the choices which were made are appropriate." (MacLean, et al, 1989, p. 247)

Traceability linkages to represent rationale would capture the *why* or *reason for* design decisions. Design rationale allows for reasoning about a system's characteristics in the process of understanding and changing it. Design rationale is an important issue in change management, as it can facilitate change while not necessarily

providing the mechanism for doing so. Tracking relationships among design objects, and understanding how and which of those objects is effected by change, is vital in the maintenance of the system.

The focus group participants were keenly aware of the need for design rationale as a component of traceability: ("The systems designer needs traceability in order to examine the logic behind the system."; "Traceability could be very useful for justifying why you did something the way you did it."; "Traceability would be good for determining what input and output are required."; "We have some artificiality built into the system—you can say this is how it's supposed to be, but is it really? You may need traceability to help you adjust requirements.")

4. Project Tracking and Management

Requirements traceability can be used very productively in project management and tracking. During the systems definition and subsequent phases, traceability is essential to ensure that all systems requirements have been met. Establishing all life-cycle phases as complete can go a long way toward guaranteeing the ease of the verification and validation process.

The project manager can use links such as status, completion date, and authorization between various components of the system for scheduling, continuity, and security. Such

information is indispensable in integrating project management into the systems development operation, and the efficient completion of project management tasks.

Focus group participants were very interested in project tracking and management possibilities using traceability. ("Without traceability, if you've lost a linkage you spend much valuable time tracing back to the original requirement."; "If you don't write down your thought processes and assumptions, and most people don't, you can't remember what you've been doing unless you have traceability."; "Humans don't go back to the requirements enough."; "Traceability should be extremely helpful with tracking costs."; "The project manager needs traceability for tracking milestones."; "Traceability would be great for the project manager's security concerns.")

5. Accountability

A major use of traceability is to provide accountability. Using traceability legitimately to communicate with the original designer of a system component, or to understand the capability of a system, is an example of such potential use. However, caution must be used when employing traceability information to enforce accountability. The use of accountability information as a means for performance appraisal may be inappropriate. A parallel could be drawn to the use of information gathered during structured walkthroughs

in systems development which should be strictly used for understanding and improving the current system and not for performance evaluation.

Some accountability information that could be captured, using traceability linkages, include: design elements *designed by*, *validated by*, and *modified by* development personnel. The availability of such information will be indispensable in maintaining and revising a system.

The focus group subjects perceived an urgent need for the accountability element tempered by constraints on its usage: ("Traceability needs to be something that humans can work with, not just a whip held over people."; "Traceability should not be used to threaten people with."; "Accountability needs to be supplemented with good communication.") They were also mindful of the future: ("Accountability implies affordability—we're going to have less resources available in the future."; "I'm sure that I'm going to want to look back in the future and ask myself who made certain decisions or where decisions came from.")

6. Personnel

Personnel are a critical component of any large-scale system. It just as important to capture how requirements relate to personnel as with other components of the system. This may involve tracing the responsibility for a requirement to a human.

A c rehensive mechanism for traceability should link the personnel component of a system to the other components. Examples of such linkages include systems functionalities *performed by* humans. This information is necessary to ensure that the allocation of requirements is complete and correct.

Focus group participants touched on this concept: ("We need traceability for human manageability.")

7. Documents/Manuals

Document traceability determines the existence of relationships between two document segments; it means that a particular document is in accord with a previous document, with which it has some type of relationship. Document traceability also ensures that all components in one document have a related *component in another document.*

> Consistency and completeness constraints apply within a document and across documents. Within a requirement specification, a requirement description may define inputs and outputs which relate to other requirements in the specification. Inconsistent references and incomplete specifications may occur and can be checked....(Horowitz and Williamson, 1986, p. 1079)

Traceability linkages to documents include *interpreted by, defined by*, and *consistent with*. Such linkages specify how to obtain a required performance from a systems component.

Our focus group subjects had considerable insight into some of the document traceability implications: ("Stakeholders are interested in having traceability to be able to write quality manuals and data dictionaries.";

"Traceability is good in that it de-emphasizes [unnecessary duplication in] documentation."; "If traceability is good, another contractor should be able to do documentation."; "Traceability is not a requirement of documentation, but it is highly desirable for documentation purposes.")

8. Dependencies

Since complex systems are composed of interdependent components, such *dependencies* should be represented and maintained. Often the inter-component dependencies are not well understood and documented.

Systems design is a complex activity involving interdependent decisions. In the absence of mechanisms to record such dependencies, over time and with changing development teams, this information will be lost. Such dependencies may span different systems components. A decision about software may be dependent on an earlier decision about hardware. As the system evolves over its life cycle, the hardware decision may be altered, leading to inconsistencies with the software that was based on the earlier hardware decision. Unless the dependencies are captured and maintained, such issues may go undetected, leading to severe system integration problems.

Another form of dependency is the fact that there may be several components needed to satisfy a requirement. As the system evolves over its development life cycle, it is

desirable to identify design or implementation elements that "partially satisfy" a given requirement. For instance, a hardware/software combination is often necessary to satisfy a given requirement. When either the hardware or software component is developed, traceability information should reflect the fact that the partially satisfied requirements are fully satisfied by performance of necessary actions.

It is possible to identify a combination of design elements that *satisfy* a requirement or are *generated by* it. An example of such a traceability scheme is the use of AND-OR graphs to represent traceability linkages. Such AND-OR graphs can be used to model a task in terms of a series of goals and subgoals. If requirements are treated as goals to be satisfied, the successive refinements can be treated as subgoals to be satisfied. The goals which can be satisfied only when all of their immediate subgoals, are satisfied are represented by AND nodes. When goals can be satisfied by any of the subgoals, they are represented by OR nodes. Liu and Horowitz model the Work Breakdown Structure (WBS) of a software project as an AND-OR graph. (Liu and Horowitz, 1989, pp. 1282-1283) This concept can be used in maintaining traceability linkages between various levels of outputs, when a logical combination of lower level outputs satisfies a higher level goal or requirement. An AND-OR graph is depicted in Figure 3.

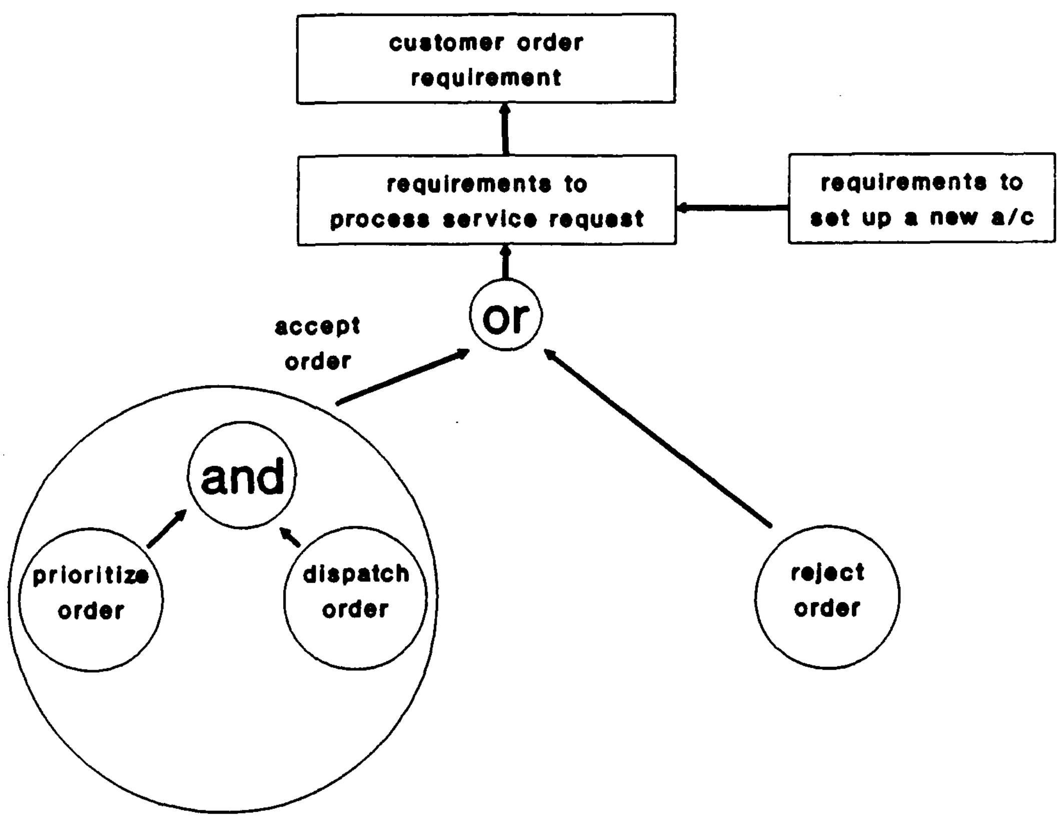

Figure 3. Example of AND-OR Graph

Yet another form of dependency can be summed up: ("The data base design has a transitive dependency.") This dependency is identified when the ("data base design requires the data flow diagram [which in turn] depends on the requirements. Therefore, requirements determine database design.")

9. Horizontal and Vertical Traceability

Vertical traceability refers to the "association of software (system) life cycle (SLC) objects of different types (typically created in different SLC processes). An example of a vertical traceability relationship would be between requirements statement and design statement." (Nejmeh, et al, 1989, p. 981) ("Vertical traceability is easy because there's a 'rule'...you explode a process and either you have to or you don't.")

Horizontal traceability refers to the

> association of SLC objects of the same type (typically created in the same SLC process). An example of this type of traceability includes parent/child relationships among decomposed data flow diagrams and the 'derived from' relationship among requirement statements. (ibid, p. 981)

("When you're moving horizontally, you're analyzing what process is inside what process.") Horizontal traceability equates to a ("subprocess transferring data to another subprocess like primitive levels have to talk to each other, etc.").

10. Automated Support for Traceability

Automated support for traceability can be extremely valuable when systems are large and/or complex. "When performed manually, the tasks are time-consuming and error-prone; moreover, users' abilities to analyze traceability data are limited by the sheer volume of data...." (ibid, p. 981) In such circumstances, "an automated software tool is an imperative, as the measuring process can become extremely onerous." (Shepperd and Ince, 1990, p. 81) As stated by Thayer and Dorfman, "There have been many cases where it appeared, at the outset, that it would be an easy task to keep track of it [manually], but when the system design is complete, and the customer is trying to understand whether all the test data really satisfies the original requirements they wrote, the automated traceability would be 'worth its weight in gold'." (Thayer and Dorfman, 1990, p. 66)

The degree of automated support can vary widely, depending on the level of sophistication warranted/desired. "The simplest [form] is a list that is tabulated by the ID of the requirement." (ibid, p. 66) This list can be changed, as needed, to support the iteration process. The use of a flexible database program and other more intricate aids can be utilized for more complex automated support.

D. SUMMARY

The issues reviewed above suggest there are many aspects of traceability which need to be considered when contemplating a traceability model for real-time, complex systems. This chapter specifically indicated that different stakeholders will have different uses for traceability, and in varying degrees.

V. CONCLUSIONS AND RECOMMENDATIONS

Based on the findings discussed in Chapter IV, recommendations on methodologies to be used in a comprehensive study, and the appropriateness of the two techniques used in this research, are presented. The need for a model of traceability is also addressed.

A. METHODOLOGIES FOR FUTURE RESEARCH

The focus of this thesis is to explore experimental methods that could help define tracing requirements in systems development, based on a laboratory experiment with 58 subjects at the Naval Postgraduate School. This study suggests that the focus group technique and protocol analysis (to a lesser extent, however) could be used successfully to identify tracing requirements.

Comparison of the two primary data-collection strategies offers some insights. Focus groups provided surprisingly interesting results. In this exploratory data-collection method, the researchers' biases do not constrain the participants. It should be noted that the moderators of the focus groups were non-experts in the traceability field; therefore, the potential for bias was minimal. In our study, many participants related concepts of requirements

traceability to their experiences in shipbuilding and aircraft maintenance, which employ similar concepts. Focus groups, including participants with real-life systems development experience, are likely to provide valuable information, even if the participants are not familiar with current traceability tools and techniques, provided they have sufficient interest in the concept. As the participants are not restricted by the researchers' ideas and predispositions, this methodology often will provide new perspectives and approaches to the problem being explored.

Protocol analysis, on the other hand, is likely to provide specific data on problem-solving behavior. Useful results can be obtained if the behavior is studied in a real-life problem-solving situation. This requirement, however, severely constrains the use of protocol analysis in future work for several reasons. First, current methods of capturing and reasoning with traceability are inadequate to provide us an appropriate real-life problem-solving situation. Second, the protocol analysis method is quite costly in terms of demands on subjects and researchers. Therefore, the use of this methodology should be restricted to a small number of subjects in a relatively well-defined area of problem solving (e.g., traceability for accountability).

B. TRACEABILITY MODEL

Findings from our study suggest that an initial model of traceability is needed. One approach to developing such a model is to understand the traceability needs of various stakeholders in the systems development process. Our study attempted to capture these needs through the eyes of the stakeholders. We believe our findings will help future researchers develop such a traceability model.

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